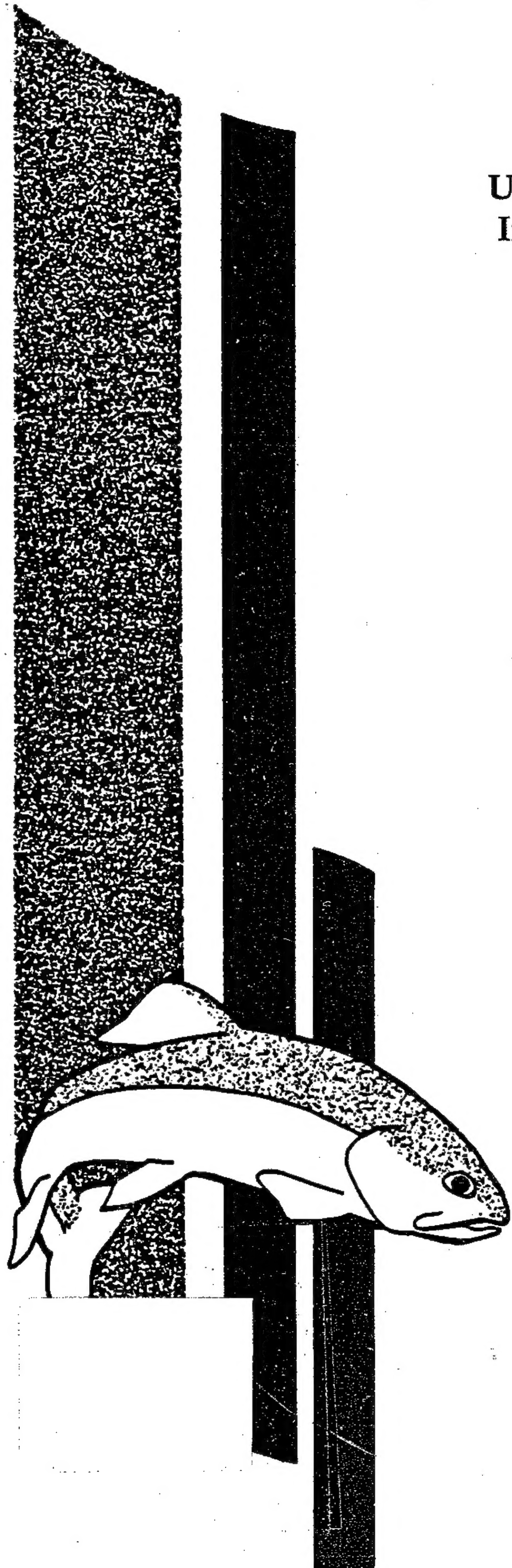

User Manual for the Small Lakes Integrated Management Model: Version 2.0

by

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ABSTRACT

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This manual provides instructions on how to operate and parameterize a model (SLIMM) designed for use by managers of small lakes in B.C. A detailed description of model structure is also provided. The model focuses on rainbow trout and is designed to assist managers in anticipating the results of a variety of management actions in three main categories: regulations, stocking, and habitat alterations. The model is based on a variety of empirical relationships that link factors such as fish growth to density. These relationships form dynamic links to lower trophic levels which are not explicitly modeled. Output is in the form of time series graphs or equilibrium values for 49 indicators.

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Table of Contents

1.0 INTRODUCTION

The Small Lakes Integrated Management Model (SLIMM) was created to provide a tool for regional management biologists to assess alternative management actions such as harvesting and stocking policies. SLIMM contains 3 basic elements:

1) a dynamic age-structured salmonid population sub-model which simulates the response of wild and hatchery populations to management actions influencing density and age-specific mortality;

2) data bases of physical, limnological and chemical information for up to 3,000 lakes in British Columbia which is used to provide input information required by the population model for lake-specific simulations; and

3) a Graphical User Interface (GUI) which allows SLIMM users to implement different management actions, alter assumptions and/or structural relations within the population sub-model, access the data base, and view the results of model simulations.

This User's Guide describes how to install SLIMM on your computer (Section 2), how to operate the model, access the data base, and how to adjust the model parameters (Section 3). The choice of parameters is discussed in Section 4 and Section 5 provides details of the model structure.

Version 2.0 of the guide and model will constitute the official published version. As modifications to the model are made, these will be available in an electronic form, with the manual in Wordperfect format, from the Research and Development Section at U.B.C. For non-Government of B.C. users, the E-mail address is: EParkins@ubc.env.gov.bc.ca.

2.0 INSTALLING SLIMM ON YOUR COMPUTER

2.1 Computer Requirements

The minimum usable hardware configuration for SLIMM is an IBM or compatible 80386DX 25 MHz system with an 80387 math coprocessor, 4 MBytes of memory, and a VGA graphics card. SLIMM must be run under enhanced mode from Microsoft Windows version 3.1. The model will run on machines with less power but it will run slowly; it may take up to 90 seconds to run a simulation. The ideal configuration is an 80486DX 33MHz or 50 MHz system with 8 MBytes memory, a SUPERVGA graphics card and monitor running in 600 x 800 mode (the SVGA driver in MS-Windows 3.1).

2.2 Installation

The SLIMM distribution diskette contains a *readme* file which also documents this installation procedure. If you have a previous version of SLIMM on your computer, delete the contents of the directory where it resides or install the new version of SLIMM in a different directory.

To install the model:

a) Insert the distribution diskette into your floppy drive.

b) Using the FILE MANAGER in WINDOWS, create a subdirectory on your hard disk where you want to install the model.(e.g. H:\WORK\SLIM)

c) Copy pkunzip.exe from the distribution diskette to the subdirectory that you have just created.

d) To unarchive the model files type:

    pkunzip a:slim

   if a: is the 3.5" drive where you inserted the distribution diskette.

e) Using a file editor (such as WINDOWS NOTEPAD), modify slim.ini so that the drive and path specified in the file correspond with the drive and path where you have just installed SLIM (e.g. change C:\SLIMM\xbs110.dll to H:\WORK\SLIM\xbs110.dll). An error message, "Can't find Installable ISAM" when starting the model indicates that this file hasn't been modified correctly.

f) Using a file editor, include the following line in your autoexec.bat file (located in your root directory):

    share.exe

   AUTOEXEC.BAT is located on your boot disc or in your root directory on your hard disc. An error message "Couldn't lock file: SHARE.EXE hasn't been loaded" when trying to save results to an EXCEL file while running SLIMM indicates that the SHARE.EXE line hasn't been added to your AUTOEXEC.BAT file.

g) Create a SLIMM program item in the MS-Windows Program Manager using the **File/New Item** menu choice as described in the Windows user documentation. An example of what to type in the **File/New Item** dialogue box is given below.

Program Item Properties	
Description:	**SLIMM V2.0**
Command Line:	**h:\work\slimm\slimm.exe**
Working Directory:	**h:\work\slimm**
Shortcut Key:	**None**

SLIMM should now be ready to run. Parameter files (*.HYP files) for version 2.0 are not compatible with the files created or distributed with previous versions of the model. Do not attempt to load old parameter files using the new version of SLIMM or the model will crash.

If you normally operate Windows in VGA mode (600 x 480 pixel resolution) you will not be able to see all of the information displayed in some of the larger windows in SLIMM. We recommend that you use SUPERVGA mode (800 x 600 pixels). To use this resolution you will need to change the screen resolution before starting SLIMM. This can be done through the following steps:

1. From the Main program group within the Windows Program Manager, open the Windows Setup Program;
2. Select the Options-Change System Settings menu choice;
3. Under the Display drop-down list box, select the SUPERVGA (800 x600) screen resolution;
4. Restart Windows as directed.

Or:

1. Exit windows;
2. Type SET at the prompt;
3. You will see a list of settings. Type SET WINVIDEO=SUPERVGA at the prompt.
4. Logout and reboot your machine.

To create a distribution diskette, go to the DOS prompt in the SLIMM directory and run MOEDIST.BAT after inserting a formatted 1.4 MB diskette in your floppy drive.

3.0 OPERATING INSTRUCTIONS

We assume that the user has a basic working knowledge of the Microsoft Windows environment. If you are not familiar with the use of a mouse, or unfamiliar with the MS-Windows 3.1 interface, please consult the MS-Windows operating system User's guide.

The interface of SLIMM is composed of multiple windows. The *Parent Window* or main screen is the first window you see after the title banner. The *Parent Window* has three elements:

1. A set of controls at the bottom of the window that affects the operation of the model and the graph panes which are displayed.

2. A set of panes which display model results and historical/future stocking rates.

3. A *Main Menu Bar* at the top of the window which allows you to access other windows which contain the data base, and parameters controlling the behaviour of the model and management actions.

3.1 Quick Start

Use this section to get the model running and change stocking rates and fishing regulations before looking at the detailed descriptions. More details for running the model are provided in Section 3.2.

Install the model using the procedure outlined in Section 2.2. and start the model by double clicking on the SLIMM icon. Click on the *Continue* button. By default, the lake seen on the screen after startup is Alleyne Lake, a hatchery monoculture lake located near Merritt in region 8. To run the model and display some results, use the mouse to click on the *Start Run Button* located on the bottom left of the *Parent Window*.

By default, graph pane 1 displays CPUE, graph pane 2 displays length at age, and graph pane 3 displays the age distribution in the catch, but these can be changed to include any of the 49 indicators (see section 3.2.2) available. To view the actual numbers behind each graph, double click on a graph pane after a simulation has been run.

The model can be manipulated in various ways. A key thing to remember is that: *After any typed changes of values, the enter key must be hit to register the change.*

Four methods can be used to change the stocking rate:

1. Drag the mouse across the *Stocking Pane* - The stocking rate will be reset to the values represented by the red bars of the histogram.

Double click the mouse on the *Stocking Pane* and the *Stocking Window* will come up. This window allows the user to change the graph pane maxima and to change the stocking rate with three other methods. These are:

2. Manual entry option - Use the mouse to highlight the radio button next to the *Manually Enter Stocking Rate* label. A spreadsheet will appear. Enter the stocking rates in numbers per hectare or numbers

per lake and the stocking weights. Use the mouse to move the icon to one of the cells in the spreadsheet. Enter a stocking value and click the mouse button to register the change. The adjacent cell will fill in with the converted figures. To use the copy and paste attributes to fill the spreadsheet, click the mouse on a cell (or group of cells) and then click on the copy button. Drag the mouse across the cells to be filled in; Release the mouse and click on the paste button. The highlighted cells will now have values.

3. Constant rate - Click on the *Constant Rate Radio Button*. Change the stocking rate by highlighting the current value with the mouse and entering a new value (yearlings/ha/yr) in the box; <u>hit the enter key to register the change</u>.

4. Historic Stocking Rate - Bring up the historic stocking rate from 1980 to 1992 by clicking on the radio button next to the *Historic Stocking Rate* label.

To compare results between runs, click on the box beside the *Overlay* label in the bottom left corner of the parent window. When an x is inside the box, the overlay option is enabled. Each subsequent simulation will be represented by different lines on the graph panes.

Try doubling the stocking rate (to 600/ha/yr) using the constant stocking rate option and, with the overlay function on, start another simulation by clicking on the *Start Run Button*.

To clear the graph panes, click the *Overlay Box* so it is disabled and click on the *Refresh Button* located at the bottom center of the Parent Window.

Change the angling regulations by clicking on the *Policy* label on the *Main Menu Bar*. Click on *Regulations* to bring up the *Fishing Regulations Window*. To view the regulations imposed on the lake, view the *Regulation Codes x Lake Frame* located at the bottom right corner of the *Fishing Regulations Window*. This box displays the lake name and the current regulation code, which by default is code 3 (Standard Regs.). Change the regulation to code 2 (Trophy Catch) and <u>hit the enter key to register the change</u>. Try running the model with a high bag limit and change the regulations to a low bag limit and overlay the result. Go back to the *Fishing Regulations Window* again. Try raising the minimum size to 30 cm. Do this by using the left mouse button to highlight the current minimum size value of 20 cm in regulation code 2. Use the backspace or delete key to remove the current value, type the number 30 <u>and hit the enter key</u>. Run another simulation by clicking the mouse icon on the *Start Run Button*.

3.2 Options

Some of the information listed below was briefly mentioned in the Quick Start Section. This section goes into greater detail about all model functions.

To begin a simulation, click on the *Start Run* button located on the bottom left side of the *Parent Window*. The model will perform a complete simulation of x time steps, (as indicated by the *# Time Steps Control*) and display the results of the simulation. The maximum number of years which can be simulated is 50.

In many instances, you will want to compare the results of one simulation with those of another

completed under a different management scenario. To do this, turn on the *Overlay* feature (click on the empty box; an x denotes *Overlay* is turned on). When *Overlay* is active, the results of each simulation are maintained on the graph panes. Each new simulation run is distinguished on the graph panes by a different line.

3.2.1 Stock Structure Control

Within each selected lake, SLIMM simulates the dynamics of up to two populations. If you select the *Wild/Hatchery* option on the *Stock Structure Frame* located on the bottom right of the *Parent Window*, SLIMM will simulate the dynamics of both wild and hatchery fish. To model the dynamics of a hatchery stock, there must either be a stocking history in the data base for the lake being simulated, or you must specify a stocking history from the *Stocking Pane* or *Stocking History Dialogue Box* (see section 3.2.2 immediately below). If you want to eliminate the wild stock from your simulations, select the *Hatchery Only* option; if you want to eliminate the hatchery stock from your simulations, select the *Wild Only* option. There is no need to select the *Hatchery Only* option if a stocking history is not specified or present in the data base.

The *Male/Female* option forces SLIMM to eliminate any hatchery stock and model the sexes of the wild stock individually. If this option is selected, parameters from the *Stock/Sex Dependent Parameter Window* which were previously stock specific (Hatchery/Wild) are now sex specific (hatchery parameters = male; wild stock parameters = female).

3.2.2 Pane Selection Control

There are 5 different types of panes that can be displayed to summarize model results for each simulated lake (see figure 3.1). The number of panes displayed on the *Parent Window* is adjusted through the *Pane Selection* control at the bottom middle of the window. By default, three graph panes and the *Stocking Pane* are displayed.

If you select a different combination of panes to be displayed on the *Parent Window*, click on either the *Refresh Button* to update the window.

3.2.2.1 Graph Panes

Graph panes display line plots of the chosen indicators at the end of each simulation. Up to three indicators can be plotted as separate lines on each graph and are distinguished by different colours for each line. Lines can be made thicker for presentation purposes (Section 3.3.1.2)

3.2.2.2 Indicator Summary Pane

The *Indicator Summary Pane* contains the average value of specific indicators for the entire simulation period. The indicators displayed in this pane are:

CPUE Kept:	Number of fish (wild and hatchery) retained per hour of fishing effort averaged over one year (in Fish/Angler Day).
Total Catch/Ha:	The total number of fish (wild and hatchery) retained annually per hectare of lake surface.

Angler Days/Ha: The predicted effort per hectare lake surface over one year.
Travel Time: The predicted travel time (hr/km) to reach the lake.

3.2.2.3 Stocking Pane

The *Stocking Pane* provides one of the three ways of setting stocking rates (# yearlings/ha) for each lake being simulated. The choices can be accessed by double clicking on the *Stocking Pane* and include:

1. **Historical Stocking Rate** - The historical stocking rate time series is read from the SLIMM data base. Change the displayed stocking rate by clicking on the *Stocking Pane* at a horizontal position close to the year to be altered. Drag the mouse across the box and draw-in the desired pattern. Another method of changing stocking rates is to double-click on the *Stocking Pane* to bring-up the *Stocking History Dialogue Box*. From this dialogue box, the user can adjust the Y-axis maxima of the *Stocking Pane*, manually enter a stocking history, specify a constant stocking rate for the entire simulation period, or reset the historical stocking pattern.

2. **Manual Stocking Rate** - Manually enter a stocking history by clicking on the radio button beside the title *Manually Enter Stocking Rate*. A spreadsheet will appear. From this spreadsheet, you can enter stocking values in either numbers per hectare or total number per lake. Add the stocking weights in grams. These values represent the number and weight of yearlings at the beginning of the model year, April 1. Using the copy and paste attributes of the spreadsheet, the user can quickly fill the spreadsheet with the desired values.

   To enter values in the spreadsheet, click on the desired position. Enter a stocking value and click the mouse button to register the change. The adjacent cell will fill in. To use the copy and paste attributes to fill in the spreadsheet: Click on a cell, Then click on the copy button and release the mouse, Highlight the cells to be filled in by dragging the mouse across them, Release the mouse and Click on the paste button. The highlighted cells will fill in with the appropriate values. These manually entered spreadsheet values are saved when the *.HYP file is saved (see section 3.3.3.6 below).

3. **Constant Stocking Rate** - Constant stocking rates are set by clicking the radio button beside the title *Constant Stocking Rate* and entering a stocking rate in the box. Press enter after changing a number in order to register the change.

Note that stocking rates are given in yearling equivalents (using a default value of 100 mm for yearling length, about 10 g) if: the constant stocking rate option is used, weights are not specified on the manual entry option; for stocking past 1992 (unless specified under the manual option); or if a stocking policy is drawn in. The length of emigrants to the lake determines their survival to age 2 in the lake (Sections 3.3.3.7) based on parameters given in Section 4.2.8.

3.2.2.4 Age Pane

The *Age Pane* displays a histogram of the annual age-structure of the populations being simulated. It is useful for tracking cohorts from pulse stocking policies as they move through the population over time. Double-clicking on the pane brings-up the *Age-Structure Y-Axis Dialogue Box*, which allows you to adjust the Y-axis maximum of the histogram. Unlike the other panes, the *Age Pane* is updated each year of the

simulation; a green bar running horizontally along the top of the pane provides a visual reference for the current year of the simulation. Because this graph is updated every year, the model runs considerably slower when the *Age Pane* is used.

3.3 Main Menu Bar

The *Main Menu Bar* is located at the top of the *Parent Window* (see figure 3.1). The *Main Menu Bar* provides the user access to the other windows which contain the data base (*Lake Info*), the parameters which control the behaviour of the model (*Parameters*), management actions (*Policy*), choice of indicators (*View*) and output options (*Report*).

3.3.1 View

3.3.1.1 Age Structure

An alternative method to see the age-structure for the last year of a simulation is to select the *View* option of the *Main Menu Bar*. Select the sub-menu *View Age Structure*. This will display a window containing a line graph of density versus age. Use this option if you want to see the final age-structure of the equilibrium population without slowing SLIMM down by updating the *Age Pane* each year of the simulation.

3.3.1.2 Plot Setup

To assign indicators to *Graph Panes 1-3*, select the *View* option of the *Main Menu Bar* and select the submenu *Plot Setup*. The 49 available indicators are grouped into the following five broad classifications:

1. Catch per unit effort (CPUE in numbers of fish/angler day)
2. Fork length (in cm)
3. Percentage of age X in catch
4. Fishing mortality
5. Assorted

The *Time Series Graph Setup Window* contains a list of the 49 indicators in the above table. The user can assign up to 3 indicator numbers to each pane by typing the indicator number in one of 3 boxes for each pane, or clicking on the desired box followed by clicking on the desired indicator to place in the box. The indicators assigned to each pane should be selected from the groups represented by the four boxes in order to keep the y-axes consistent. The default setting includes CPUE in Pane 1; mean length in catch, length at age 2, and length at age 4 in catch in Pane 2; and % age 2 and 4 in catch in pane 3.

To adjust the Y-axis scale of each *Graph Pane* insert the appropriate value in the y-axis minimum and maximum boxes for each graph pane. You can also alter the y-axis title, and the display of x labels and the number of ticks which appear on the y-axis.

Click on the *Colors Button* in the *Time Series Graph Setup Window* to adjust the color and line thickness for the time series graphs. To change the color of any of the graph elements (graph background, lines 1-3), click on the element in the *Colors Dialogue Box* and then click on the desired color on the

color palette. If you select the Thick Lines/no line patterns check box (an x will appear when this option is selected), the lines on the graphs will be thicker, but if you use the overlay option, you will not see different patterns for each successive overlay. The thick line option is useful for presentation purposes.

Table 3.1 Summary of 49 indicators used in the SLIMM.

Indicator Name	Description
CPUE Hatchery or Wild	Total # fish caught (including released) /angler day (Hatchery or Wild)
CPUE Kept	Total # wild and hatchery fish retained /angler day
Mean Length Hatchery or Wild	Average fork length of all hatchery or wild fish caught (including released) in cm over the year
Mean Length Kept	Average fork length (cm) of wild and hatchery fish retained over the year
Length Age **X** /Hatchery, Wild	Fork length (cm) of Age-**X** hatchery or wild fish in spring
% Age **X** in Catch (retained) /Hatchery, Wild	% of kill that is Age-**X** (hatchery or wild)
Age **X** Fishing mortality	Percentage of age class **X** mortality attributed to fishing.
Wild / Hatchery recruits	Ratio of wild to hatchery yearlings in the lake
Wild Recruits/Ha	Density of wild yearlings in the lake (#/ha) in spring.
Numbers/Ha > 2 Yrs Old	Density of fish (wild and hatchery) > 2 Years old (#/ha)
Yield (# / ha)	Numbers of fish retained per hectare
Mean Age in Lake	Average age of all fish in the lake
Mean Age in Catch	Average age of all fish in the catch
Effort/Ha	# angler days /ha lake surface
Eggs Deposited / m^2	Eggs deposited/m^2 of spawning (not total) stream area
Kg / ha > 2 yrs old	Biomass of fish (wild and hatchery) > 2 years old (kg/ha)
Yield (kg / ha)	Weight of fish retained per hectare
Return to Creel	% of Hatchery yearling equivalents harvested

3.3.2 Lake info

Lake Info is used to access the SLIMM data bases and for selecting lakes to simulate. There are two types of data bases, DBASE IV (*.DBF) and ORACLE. The DBASE IV files are compatible with a variety of applications including EXCEL. For users on the B.C. MOE Provincial wide area network, SLIMM will also be able to access a centralized ORACLE data base (Fisheries Aquatic Data Base), which contains inventory data on B.C. lakes and streams and is maintained in Victoria. The connection to the ORACLE data base will not be incorporated into SLIMM until the Fisheries Aquatic Data Base is released.

To access the *.DBF data bases, select the *Lake Info* menu on the *Main Menu Bar* as well as the sub-menu titled *Lake Info* and the *Lakes Data base Window* will appear. A default *.DBF data base (SLIMM.DBF) was loaded as you entered SLIMM. This default data base contains a selected set of small lakes that have more complete data sets. These represent a variety of types of systems such as coastal versus interior, wild versus hatchery and monoculture versus mixed species. Use the radio buttons to display lakes in this file that are situated in the various Regions.

To access other *.DBF files, including complete files for each Region, select *Files*. Choose *.DBF file from the list. The current version of the SLIMM data base only contains *.DBF files from regions 1-5 and 8 (e.g. REGION1.DBF) as well as the default lake file, SLIMM.DBF.

After retrieving a *.DBF file, click on a specific lake name to view the available inventory and stocking data. Double-click on the lake name to include it in subsequent simulation runs. Lakes selected for a simulation will be highlighted by an 'x' beside the lake name. Double-clicking on a selected lake name will de-select that lake and remove the 'x'.

The stocking information contains a history of the number and weight of fish stocked since 1980 by different stocking types. The yearling equivalent stocking type combines all stocking types into a single number and weight per year. Fish stocked as fry and fall fingerlings are converted into numbers of yearlings of a given weight based on growth and survival calculations explained in Sections 3.3.3.7 and 4.2.8 of this guide. The yearling equivalent numbers and weights displayed in this window (and in the manual stocking rate window-historic option) are based on densities which are low relative to the competition index and therefore the size, as yearlings, of fish stocked as fry or fall fingerlings may be overestimated. During a simulation, the current simulated density and the competition index are used to calculate the number of yearlings produced, and the yearling size, of various types of stocked fish in order to more accurately reflect the true situation.

While you cannot edit the lake data base files from SLIMM, it is easy to do it from EXCEL. Simply load the file into EXCEL, and edit the record. You can add records to a file (say SLIMM.DBF) from another file (say REGION1.DBF) by copying the entire row from one file to the other. To add a new lake which currently isn't in the data base supplied with SLIMM 2.0, insert a blank row in an existing file (at least one record below the field names) and enter the new information. When you are done making changes to the file, highlight all records (including the field names) and select the Data-Set Data base menu items in EXCEL. Then save the file as a DBASE IV file by selecting the Save As... item from the Files main menu item in EXCEL.

3.3.3 Parameters

Variables controlling the dynamics of the modeled populations and their response to management actions can be viewed and/or modified through a series of windows accessed from the *Parameters:Main Menu Bar* item. Some parameter windows are more complex than others. Additional details on the function of the more complex ones are located in Setting Parameters (Section 4). The effects of many parameters can be visualized using the *View* options which are present in many windows. The values of many parameters can be varied with slider controls which can be either dragged or clicked-over with a mouse. The size of the jumps (when the slider is clicked) is fixed in the model code as a proportion of the maximum value displayed when a window is opened. To increase the maximum value of a slider, move the slider to the right hand edge of the slider track, and type a new maximum in the adjacent text box (don't forget to hit return after you've entered the number).

3.3.3.1 Stock/Sex Dependent Parameter Window

The majority of parameters in the *Stock/Sex-Dependent Parameters Window* affect how the model predicts changes in growth in response to fish density. Parameters in this window are either stock(hatchery/wild)- or sex-specific (male/female), depending on which option is selected from the *Stock Structure Frame* on the *Parent Window*. Natural survival is the annual survival of age-2 and older fish. Clicking on the *View* option brings up a graph which displays length-at-age on April 1.

The Walford slope and intercept parameters control the shape of the length-at-age graph. The Walford intercept can be determined by one of three options controlled by the radio buttons in the *Growth Prediction Method Frame* of the *Stock/Sex Dependent Parameter Window*. The three options are: the slider controls, prediction by lake pH, and use of the Regional average. The regional averages of the Walford intercept and pH are listed in the *Parameters; Regional Growth Window*. With the *use Walford intercept above* option selected, the *View* option can be used to observe the effects on size-at-age of alterations in the Walford intercept and slope parameters.

Two features alter the overall height of the growth curves: the *competition index* and the *growth curve calibration density*. The *competition index* is the density of fish in the lake (total #/ha) at which the length of age 1 fish is reduced to 1/2 the maximum length observed at very low fish densities (Section 5.1).

The *growth curve calibration density* value in the *View Length-at-Age Setup* establishes the density for which the viewed growth curve is calculated. This density is in numbers/ha and is compared directly to the competition index. The density value for the most recent simulation is given in the yellow box labeled *Current total #/ha in Lake 1*. This value can be used when calibrating the growth curve (see Section 4.2.1).

The weight and time at lake entry are also entered in the *View Length at Age Setup Box*. These values are needed to provide a starting point for the growth curve in the lake and to account for the reduced growing season in the lake which fish experience during their first year of life. The weight at stocking is entered in the *Entry Weight Box*. The time and life stage at entry are controlled with radio buttons; the user can adjust the proportion of a year's growth which emigrant fish will experience.

3.3.3.2 Catch Parameters Window

The three middle parameters in the *Catch Parameters Window* (minimum recruitable length, length at 1/2 max. vulnerability, vulnerability-curve shape parameter) define a relationship which predicts the vulnerability of each age class to fishing based on the predicted size. To view the vulnerability as a function of size and the effect of these three parameters, click on the *View* option from the spreadsheet.

The catchability (q) parameter is used in the model to predict fishing mortality and catch and is equivalent to CPUE/N_0, where N_0 is the number of vulnerable fish available at the beginning of the fishing season. An alternative definition of catchability is the proportion of the fully vulnerable population in 1 hectare caught by one unit of effort (angler-day).

In SLIMM, effort and stocking rates are specified on an aerial basis (angler days/ha) based on the entire surface area of the lake. Since most of the fish and fishing action are concentrated around the lake

perimeter, the density of fish "seen" by the angler is higher than the model would predict using the entire lake surface. The lake area associated with the q parameter can be used if the area of the lake where catchability was measured is known. To account for this, the model automatically adjusts the catchability. This adjustment can be turned off by removing the x in the *Lake area adjustment for q is enabled Box.* The proportion of fish voluntarily released can be altered by use of the slider. This rate of release is for legal sized fish; it is assumed that all undersized fish will be released.

3.3.3.3 Effort Related Parameters Window

The base or average effort level for each lake is calculated by taking into account the *Regional Base Effort, Travel Time Parameter* (which uses lake accessibility as input), and *Regional Base CPUE. Regional Base Effort* and *Regional Base CPUE* are parameters that have been estimated separately for each management region (1-8) from empirical data on effort, CPUE, and accessibility. The *Regional Base Effort* parameter essentially represents effort that would occur in a lake having typical fishing quality (CPUE, size) if that lake had zero travel time from the nearest town in the region. The model takes the base effort level and makes it dynamic with changes in CPUE. This relationship can be viewed by clicking on the box next to the *View Effort-CPUE* label at the bottom right corner of the window.

If the actual effort value for a lake is known, the default effort values can be replaced by fixed effort levels. This is done in the *Effort Parameters Window* by clicking on a box near the bottom of the window labeled *Hold angler days / ha at Constant Level*, typing the effort value in the box which appears, and hitting the enter key to register the value.

The *proportion of effort lost in catch and release situations parameter* allows the user to specify a proportion of fishing effort that is lost in catch-and-release situations (i.e., when bag limit is zero).

3.3.3.4 Season Dependent Parameters Window

This window allows the user to modify the catchability (q) parameter and proportion of effort due to seasonal factors. The effort proportion values must sum to one across all seasons. The seasonal catchability factors are simply scalars, and do not have to sum to one.

3.3.3.5 Rearing Habitat Parameters

The top section of this window allows the user to enter an estimate of the total area of stream available for rearing and spawning. The average stream width, average stream length, % rearing habitat and % spawning habitat are lake specific values to be entered by the user. The number of inlet and outlet streams are read from the data base and cannot be altered. The total stream rearing area is calculated as the product of stream width * stream length * number of streams * % rearing area in terms of $100m^2$ units. The maximum egg density parameter is used to model density dependent egg survival (See Section 5.2). A slider to allow for the effect of annual variation in discharge has been disabled but will be activated when SLIMM is connected to a stream discharge data base.

The recruitment sub-model predicts the number of yearling recruits entering a lake based on a simple stream production model and the above mentioned estimates of the amount of rearing habitat in the streams. The *Rearing Habitat Parameters* section predicts the carrying capacity of naturally produced fish (habitat capability) for each stream life history stage by using a model based on alkalinity and fish

size (Section 5.5.1). The alkalinity model predicts juvenile densities in optimal habitats; the rearing habitat quality multiplier (0-100%) can be used to reduce these estimates and affects the predicted capacity displayed in the yellow boxes.

Fish weight and rearing density for each of four life history stages can be entered manually. This option is enabled by clicking the mouse on the box beside the label *User-Defined Rearing Capacity*. For comparison, this section displays the predicted rearing habitat based on fish weight and alkalinity of the stream for the currently selected lake.

3.3.3.6 Stream Recruitment

Factors which limit the production of fish in streams are modified through this window. The top section of the window contains sliders which set survival rates of the various life history stages.

The bottom section of the window uses the slider values in conjunction with parameters from the *Rearing Habitat Window* to calculate and display the numbers of fish migrating at each life history stage from stream to lake. The *Habitat Capacity* for adults is the fecundity (# eggs/female). The *Predicted Abundance* for adults is the number of adults needed to produce the capacity of eggs. The *Habitat Capacity Column* values for eggs to 3+ parr are obtained from the rearing habitat window.

The *Predicted Abundance Column* takes the number of eggs and obtains the values for the various life history stages by surviving the eggs and later life history stages by the rates given by the sliders in the upper section of the window.

The column labeled *% Voluntarily Migrating* can be altered by the user. The *# Displaced Column* is the difference between the *Habitat Capacity Column* and the *Predicted Abundance Column*. The *Total Migrating Column* is the sum of the *% Voluntarily Migrating* and the *# Displaced Column*. This value is the total number of migrating fish in each life history stage. The box labeled *Total Yearling Equivalents* is calculated using the size survival rates given in the *In Lake Juvenile Survival Window*.

3.3.3.7 In-Lake Juvenile Survival

This window establishes a size survival relationship for fish in the lake until age 2. The maximum survival rates displayed in the top two boxes can be altered by the user in the *Stock/Sex Dependent Parameter Window* (Section 3.3.3.1). The three sliders control the survival versus size relationship of the fish until age 2. This relationship can be seen by clicking the mouse with the icon on the box labelled *View function (for wild-yearlings)*. The parameters in the lower section of the window account for the decreased amount of time spent in the lake for summer fry and fall fingerlings and the subsequent effect this has on annual survival rates. Hatchery fish are assumed to survive poorly compared to wild fish; the box labelled *Proportion increase in size-dependent mortality applied to hatchery fish* establishes the increased mortality of hatchery fish. The default value is 0.1, meaning hatchery fish suffer 10% greater mortality than wild fish of the same size. A saturating relationship is used to set the maximum yearling capacity in #/ha.

The survival of fry, fall fingerlings and yearlings entering the lake is assumed to follow the same survival versus size curve (Section 4.2.8). The survival to yearling of fry and fall fingerlings is taken from this curve and adjusted to reflect a partial year in the lake. Yearling sizes of fry and fall fingerling are

calculated using growth increments read off the Walford plot (Section 4.2.1, Fig. 5.1) which are adjusted down to reflect a partial year in the lake. The survival of fry and fall fingerlings as yearlings is read off the survival versus size curve.

3.3.3.8 Spawning and Fecundity.

The spawning/fecundity relationship is a regression line which can be altered by the user. All fish greater than the minimum spawning lengths will mature and spawn. Spawning mortality is applied maturing fish in addition to annual natural mortality (Section 3.3.3.1). If the fish are stunted and do not reach normal spawning size, all fish are assumed to mature at a specified minimum spawner age with a specified fecundity. The proportion of hatchery fish returning to spawn in the natural habitat determines the proportion of fish actually reproduce after maturing.

3.3.3.9 Saving and Restoring Parameter Files

Parameter files (*.HYP) are ASCII text files which contain all the information displayed in the parameter windows as well as the regulation code assigned to all lakes which are being simulated. These files also store information on lake selection, lake data access, stock structure, and graphics configuration. The file SLIMM.HYP is the file which is brought up at the start of the SLIMM model. To save the model in its altered form, use the *Files/Save Option* from the *Parameters:Main Menu Bar* item to save all the changes to the file. This file can then be retrieved during a later session (using the *Files/Restore Option*) to restore SLIMM to the exact state that it was in when the parameter file was last saved. If the user wishes to bring up a particular set of lakes at the beginning of each session, name that file SLIMM.HYP. *.HYP files from previous versions of SLIMM are not compatible with the current version. If you try to load old *.HYP files, the model will crash.

3.3.4 Policy

3.3.4.1 Regulations

Harvesting policies can be viewed and manipulated through the *Fishing Regulations Window* accessed from the *Policy:Main Menu Bar* item. In the model, one of five different regulatory policies (regulatory types) can be assigned to each lake being simulated. The policy choices can be modified as can the assignment of regulatory types to specific lakes. The user can change the regulation code by altering the number in the box located in the lower right corner of the window.

To save changes to the regulatory policies to an ASCII text file (*.REG), use the *Save on File Option* from the *File Options* menu-bar item on the *Regulations Window*. The default file name is SLIMM.REG. To restore a previously saved regulations file, select the *Restore File Option*.

The hooking mortality rates associated with the different fishing regulations can be viewed by clicking on the *Hooking Mortality* menu-bar item on the *Regulations Window*.

3.3.4.2 Stocking

This menu-bar item allows the user to bring up the stocking window. The outcome is identical to double clicking the mouse on the *Stocking Graph Pane*.

3.3.5 Run

This main-menu bar item allows the user to start, overlay and stop the model. The outcome is identical to using the *Start Run*, *Stop Run*, and *Overlay boxes* located at the bottom left hand corner of the *Parent Window*.

3.3.6 Report

3.3.6.1 Send results to file

After selecting this item, either enter a new file name or select an old file name where results will be stored. A set of results will to be stored each time the *Run Button* is pressed until the check mark in front of this sub-menu item is removed by selecting it again.

Values in the model are either *Parameters* (input by the user, eg. stocking rate, constant effort level, survival) or *Indicators* (output by the model, eg. CPUE, fish size, length at age). This menu item writes up to 3 selected *Parameters* and all the *Indicators* (see *View:Plot Setup* for a list) to a data base file that can be read by EXCEL. If the *Save Results for Year 30 Only Box* is checked, one line, representing the values of the indicators in the last model year, will be printed each time the model is run. If this *Box* is not checked, one line per year is written to the file each time the *Run Button* is pressed. <u>This option can generate large files if not turned off when saving of output is not required</u>.

This function is useful for storing and summarizing the results of many runs. For example, CPUE or other indicators can be examined as a function of stocking rate. Check the *Constant Stocking Rate Box* (in the *Stocking Rate Window*), select *Constant Stocking Rate* as one of the three parameters and save 30 year results only. Now run the Model a number of times with different stocking rates. Load the data base file (saved as a *.OUT file) into EXCEL and use EXCEL to plot the results. <u>The output file is a dBase file but uses a .OUT extension rather than the usual .DBF extension.</u> When opening the .OUT file in EXCEL; Go to the SLIMM directory, type *.OUT in the file name box of the Open File Dialogue Box and Choose the file that you wish to open.

3.3.6.2 Print Graph

To send the graphic output of the model to a printer, select the *Report:Main Menu Bar* and the *Print Graph* option. If the printing is not successful, you will need to install a printer from the *Control Panel* within the *MS-Windows Program Manager*. Instructions for installing a printer are given in the MS-Windows user's guide.

4.0 SETTING PARAMETERS

4.1 Introduction

Setting model parameters involves supplying a range for each parameter value either from the literature or local knowledge. Recent literature was examined with a computerized search of Aquatic Sciences and Fishery abstracts. This procedure reviewed abstracts from the recent primary literature. The list of abstracts resulting from this search was large (>300), however the number of references containing usable data was small (<20) suggesting that, with the exception of hooking mortality (Dotson 1982, Wydoski, et al. 1976, Marnell and Hunsaker 1970), the specific information needed for this model was not common in the recent primary literature. Important data, such as differences between hatchery and wild growth rates, survival rates and vulnerabilities to angling were not available although the need for this information has been documented (Wiley et al. 1993).

Information was available on different species of salmonids. For example, Hume and Parkinson (1987) summarized data on stream survival of age-0 to age-1 salmonids but only one of ten studies examined rainbow trout. In many cases, data from other salmonid species will be useful in quantifying values for parameters such as egg mortality or juvenile stream survival.

Older and grey-literature publications were searched using a combination of citation searches and Science Citation Index. Some of the best data available was not in the primary literature. For example, Stringer et. al (1980) provides the best information on rainbow trout survival rates planted at different life history stages in the Kamloops area. Nelson (1987, 1988) are other examples of secondary literature which was difficult to find. We expect that useful, unpublished information will continue to surface as the data requirements for the model are more widely circulated.

4.2 Setting Model Parameters

This section contains the recommended values and ranges (in brackets) for all parameters in the model, along with the background information that these recommendations are based on. Parameters are listed in the order (top to bottom) that they are encountered under the Parameter menu item in the model. Default parameter values are summarized in Table 4.1 and are included in the SLIMM.HYP file supplied with the model.

4.2.1 Stock/sex Dependent

Stocks can be designated as hatchery and wild or male and female. Stock or gender specific parameters are therefore needed for natural survival, growth, and angler-vulnerability of these groups. Although generic values for each parameter are available, the literature search and discussions with the Provincial fisheries biologists suggest that stock specific parameters are not currently available. Some studies examine differences between "domestic" and "wild" salmonids; primarily with brook trout and brown trout (see references in from Burrows 1993) but also with rainbow trout (Ayles 1975). These studies provide little stock specific information for this model since the majority of hatchery rainbow trout in British Columbia are produced from wild parents. The differences between genders has been partially examined in studies of precocious maturation and a few studies have examined differences in stock type but information concerning growth rates, mortality schedules, and vulnerability to harvest does not appear to be available.

Natural Survival: 80%/yr (50-90). This is the annual survival of immature fish after their second scale check (in April) and is assumed not to change until the fish reach sexual maturity. Measured survivals of 50-80% for age-1 rainbow (Stringer et al. 1980, Johnston et al. 1991, Havens and Sonnichsen 1992) are presumed to establish a lower limit. Stringer et al. (1980) lists the survival rates of yearlings to be 48%. Rawston (1973) documented a mean natural survival of 45% (range 33-51.5%) for hatchery fish planted at catchable size in California. Natural survival was 65% from age 0+ to 2+ in Marion Lake, B.C. (Sandercock 1969). Over winter survival of rainbow trout in a small Michigan lake was close to 100%, with 86% total recovery over two years (Alexander and Shetter 1969).

Survival is assumed to be independent of density at this stage but juvenile survival can be density dependent (see Section 4.2.8).

Walford Growth Intercept: Productive monoculture lakes 28 cm (24-30), Productive mixed species lakes 20 cm (15-25). The Walford intercept represents the intercept of a plot of length at age t+1 versus length at age t (see Figure 5.1) under low density conditions. A close approximation is the length of a fry which has spent one entire year (July to July) in the lake at very low trout densities. In contrast to the slope, the Walford intercept is dynamic (varies through time as a function of fish density in the lake). High elevation, monoculture lakes in Colorado (2400 - 4000 m) have walford intercept values of 15- 17 (Nelson, 1987). Based on experience with productive barren lakes, maximum values for this growth parameter for B.C. lakes approach 30 cm.

Walford Growth Slope: 66% (60-80). The Walford slope represents slope of a plot of length at age t+1 versus length at age t. The structure of the model assumes that the slope is not dynamic, that is, it does not change with density over the coarse of a simulation. The mean value for approximately 100 lakes across B.C. is 59% (see *Run Growth Analysis* in SLIMM). This value is probably biased downward because of size-selective harvest of fast growing fish but this analysis suggests that slopes are similar across a wide variety of lakes. If some estimate of density and a length-at-age is available, the intercept and slope parameters can be adjusted to mimic the empirical curve. Decreasing the slope lowers the size of older fish only whereas changing the intercept lowers the size of all age-classes.

Competition Index: 600 fish/ha (400-1000) for productive monoculture, much higher for mixed species lake, lower for less productive lakes. The competition index is the density (total numbers/ha) which reduces the dynamic Walford intercept by 1/2 (see Section 5.1). A close approximation is the density that induces a 50% reduction in the 1st year growth (Walford intercept). The effect of competition varies among lakes and depends on factors such as productivity and the presence of coarse fish.

The SLIMM modelling exercise has identified information on the competition index as the most critical data gap in small lakes management. Explicit values of the competition index are not available in the literature but estimates can be inferred in some cases. Preliminary analysis of data from a series of small, productive monoculture lakes (Johnston and Parkinson, in prep.) suggests that, for these systems the competition index is in the range of 600-1000 fish/ha. Mixed species lakes are likely to have very high competition indices since growth of trout is suppressed, even at very low trout densities, by a large, non-salmonid fish biomass. Less productive lakes would have lower competition indices since growth of trout at very low densities is similar to that of more productive lakes but growth declines more rapidly with increases in trout density.

Estimation of the competition index is complicated by the interaction between growth and survival. Havens and Sonnichsen (1992), working in Alaskan lakes, found a density dependent effect on survival

but the relationship between density and growth was less clear. Over the range of densities, 20-360 fish/ha, the reduction in first year growth was small. This failure to see a reduction in growth may be linked to the effect of density on survival. A reduction in growth may not be observed because effective densities at higher stocking rates were much lower than expected because of low survival at high density.

When some growth data are available, the values of the growth parameters and competition index can be fitted to the available data. Ideally, two growth curves would be available: one at very low densities and one at a higher, specified density. The steps are:

1. Set the *Growth Curve Calibration Density* to a low value (5) and the competition index to a high value (500).
2. Using the view option, adjust the Walford intercept and slope so that the growth curve in the *View Option* approximates the empirical growth curve measured at low density.
3. Set the *Growth Curve Calibration Density* to a higher density (yrlgs/ha) for which an empirical growth curve is available.
4. Adjust the competition index (without adjusting the Walford growth parameters) so that the growth curve in the view option approximates the empirical growth curve measured at higher density.

In many cases, a low density growth curve will be not be available for the lake in question. Maximum growth rates for yearlings stocked at 10 cm in productive, monoculture lakes in the southern interior of B.C. are 35 and 60 cm at age 2 and 4, respectively, with an asymptotic length of about 70 cm at older ages (data on file). For monoculture rainbow, growth at very low densities is probably limited by physical conditions rather than food availability. This suggests that maximum growth rates should be only adjusted to reflect the growing season and temperature regime, and not lake productivity, relative to mid elevation (1000-1500m) lakes in the southern interior. In the presence of other fish such as redside shiner, asymptotic lengths at low trout density are limited by food availability and are rarely greater than 45 cm.

Vulnerability: 1. Differences in angling vulnerability among stocks do occur (eg. Trojnar and Behnke 1974) and this parameter is included to allow for situations where vulnerability differences are known or suspected to occur.

4.2.2 Regional Growth Parameters

This window provides a reference for the Walford intercept and pH values for the *Parameters; Stock Sex Dependent Window*. The values in this window were obtained from empirical growth rate data and represent mean values for Walford intercepts and pH for each region. Predicting the Walford intercept by regional or lake specific pH values can be used if no other information is available with respect to a length at age curve.

Other physical and chemical parameters such as TDS and/or mean depth can be used to predict growth. TDS and shoal area are the basis of the current B.C. stocking formula (Stringer et al. 1980). Donald and Anderson (1982), using stepwise multiple regression, attributed 42% of the inter-lake variation in weight at age 2 to variation in total dissolved solids, 30% to stocking density and 3% to mean depth. The low correlation between growth and these physical and chemical factors suggests that regional growth parameters are a poor substitute for lake specific data.

4.2.3 Catch parameters

coefficient of variation in lengths: .107. This parameter represents the standard deviation/mean of fish length of a given age and is assumed to be constant over all ages. The value of 0.107 came from age 2 and 3 rainbow trout from Kentucky and Alleyne lakes in the Kamloops Region of British Columbia (Parkinson et al. 1988).

var/mean ratio of catch/angler: 2.3. This parameter describes the relationship of catch rates among the anglers in terms of variance over the mean for a negative binomial distribution. It is used to model the fraction of the catch above the specified bag limit by assuming a negative binomial distribution of catch rates (lots of anglers with low catch rates, a few anglers who know what they are doing!). Mathematically, the binomial distribution has two parameters, the mean and a k value representing skew. In the model, the mean catch rate (fish/day) is obtained from the model simulations. Skewness is an input parameter but k has been replaced by the related variance:mean ratio. Naito (1992) fitted a negative binomial distribution to data from Alleyne and Kentucky lakes and obtained a mean of 0.52 (fish/day) and a k of 0.4. Using a formula from Southwood (1978, p.40), these values of give a variance:mean ratio of 2.3.

The variance:mean ratio, rather than k, is used as the skewness parameter because variance:mean ratios can easily be calculated from CPUE (fish/day) data, if a fit to the negative binomial is assumed. Simply calculate the variance (not standard deviation) and the mean of the catch rates for individual anglers and take the ratio. Higher variance:mean ratios indicate that the catch-frequency distribution is more skewed (a few anglers are catching most of the fish).

Minimum recruitable length, length at 1/2 maximum vulnerability and vulnerability-length curve shape: 14 cm, 28 cm, 4. These parameters describe the position and shape of the relation between length and vulnerability to angling. There is no empirical information describing this curve for rainbow trout but Rieman and Myers (1990) provide data for kokanee. Their curve suggests an exponential increase in vulnerability between initial recruitment at <20 cm and the maximum size in the population (28 cm). Assuming that vulnerability ceases to increase exponentially at 28 cm, an empirical fit of the Rieman and Myers data gives a minimum recruitable length of 14 cm, a length at 1/2 maximum vulnerability of 28 cm, and a vulnerability-length curve shape of 4.

Catchability: .004 (.004-.04). Catchability can be thought of as the proportion of the fish removed from one hectare by one angler-day of effort. A value between 0.004 and 0.015 is a reasonable starting point. Data in Alexander and Shetter (1969) give a catchability of .024.

Catchability is the key link between fish density and CPUE but it is lake- and season-specific and is therefore difficult to specify precisely. Similar CPUEs can be generated by high fish densities combined with low catchability or low densities combined with high catchability. The biological parameters within the model should be used to establish the density of fish in the lake and then the catchability can be used to as a final adjustment to fit model CPUE to observed CPUE for a lake.

Lake area associated with q: 6.5. This parameter is the area of the lake on which q was measured. The default value is from Alexander and Shetter (1969).It is used to scale the catchability for simulated lakes which have different surface areas. See section 3.3.3.2 for more details.

Percent Voluntarily Released: 10. This parameter is lake specific and depends on factors such as the

attitudes of anglers, size of fish and CPUE. The default value comes from data on Alleyne and Kentucky lakes where almost all fish over 25 cm are retained.

4.2.4 Effort Parameters

Our ability to set parameters for a dynamic effort response is currently limited. In SLIMM, effort is assumed to respond to rapid changes in abundance within each fishing season (see Section 5.4), however a sharp decline in CPUE in Alleyne Lake in 1987 failed to produce a significant effort response (Parkinson 1990). In simulating a single lake, the dynamic effort response should be disabled by setting the effort to a constant based on empirical data. Standardized weekend boat counts can be converted to estimates of angler-days using Tredger (1991). In the absence of empirical data, the model will use the regional average listed in this window.

SLIMM has identified the factors that control the movement of effort as a major data gap in our understanding of the dynamics of the small lake fishery. While the recommendation at present is to ignore the dynamics of effort, a dynamic effort response is unquestionably an important factor which will tend to frustrate attempts to improve angling quality on individual lakes.

4.2.5 Seasonal Parameters

The allocation of effort between the seasons and seasonal catchability will vary from lake to lake and region to region, however, the results generated by the SLIMM are typically not very sensitive to changes in these parameters. We suggest using the effort distribution calculated by Naito (1992) for four Kamploops area lakes unless there is good lake specific data available. After setting the winter proportion to .10 (winter was not covered by Naito's data), these values are: spring .42, summer .28, fall .20.

Summer CPUE in three Okanagan Lakes was about 70% of that in the spring (E.A. Parkinson, data on file). This, and anecdotal evidence from experienced anglers, suggests that catchability is highest in the spring (1.0), lower in the summer (0.70) and higher again in the fall (0.90) and winter (1.0).

4.2.6 Rearing Habitat Parameters

The parameters in this pane establish the capability of the stream to produce juvenile outmigrants. The actual number of emigrants produced depends on the habitat capability combined with various parameters defined in the *Stream Recruitment Window.*

Many of the parameters in this window are lake specific: Average Stream Width, Average Stream Length, % Rearing Area, % Spawning Area, and the # Inlet and Outlet Streams. Currently, the Provincial lakes data base lists only the number of inlet and outlet streams instead of the size or quality of habitat. Specific habitat quantity and quality information is only currently available from regional reports, data-on-file and personal knowledge. Development of the SLIMM has identified rearing habitat parameters as a major data gap in the Provincial Lakes Data base.

Sensitivity of Rearing Area to Changes in Discharge. Disabled. The use of the sensitivity to discharge feature depends on accessing a discharge data base which is currently not available.

Maximum Egg Capacity: 3,000 /m^2. Experiences with spawning channel management suggest that the maximum number of eggs that can be deposited per unit area of spawning gravel is in the order of 3,000-

5,000 eggs/m^2. In a pink and chum salmon stream where most of the area was used for spawning, maximum numbers of fry were produced at egg deposition rates of 3,000 to 4,000 eggs/m^2 (McNeil 1969). Elliot (1987, 1993) found that maximum fry production in a brown trout stream occurred at much lower densities (40 eggs/m^2) when averaged over the entire area of the stream suggesting that, in at least some streams, much of the area is unsuitable for spawning.

Alkalinity-Based Rearing Habitat Parameters: Constant=1.58, A=0.97, B=0.45. These values are taken from an analysis by R. A. Ptolemy (see Section 5.5.1) and represent predicted densities in optimal quality habitat.

Lake specific information on habitat capability, perhaps generated by methods other than the alkalinity-based equation, can be entered using the *User-Defined Rearing Capacity Option* at the bottom of the window. Four life-history stages are listed, with the opportunity to enter the weight and carrying capacity at each life history stage. The weights are used to determine the average annual weight (across different emigrant ages) of wild emigrants to the lake.

4.2.7 Stream Recruitment

The parameters in this pane establish the number of juvenile emigrants to the lake given the number of eggs deposited and the habitat capability for eggs, fry and parr. Predictions in the SLIMM can be very sensitive to survival at any life history stage. For example, when populations are limited by the amount of spawning habitat, population densities in the lake can be directly proportional to egg-fry survival.

Egg survival: 15% (5-40). This parameter should reflect the egg-to-fry survival at relatively low densities since egg survival at high densities is limited by the spawning ground capacity. Egg saturation of spawning gravel has been reported in various species of salmonids (Elliott 1993, McNeil 1969).

Maximum egg survival of rainbow trout is close to 100% under hatchery conditions but survival under natural conditions is often much lower because of a variety of factors including: egg deposition density, mechanical disturbance, low water levels, temperature extremes, dissolved oxygen levels and a suite of predators, pathogens and parasites (McNeil 1969). Reported survivals in the literature cover a wide range: steelhead, 75-86%, (Briggs 1953), (Shapavolov and Taft 1954); kokanee spawning channels, 10-70%, (Hutchinson 1987, Thorp 1987); rainbow trout, 11- 20% (Allen 1951); Atlantic salmon 15-30% (Bley 1987); steelhead, 2-12% (Ward and Slaney 1993); kokanee, 4.2%, (Fleck and Andrusak 1977); rainbow trout, 1.9% (Sandercock 1969); rainbow trout, 0.5% (Martin 1987). Although extremes do occur, most streams with normal temperature regimes, flows and gravel quality should have egg to fry survivals in the 10-30% range.

Summer fry survival: 50% (30-80%). This parameter should reflect the survival of fry at relatively low densities since surplus fry at high densities are presumed to emigrate involuntarily in the fall (ie. emigration, <u>not</u> survival, is assumed to be density dependent). Oversummer mortality rates in steelhead and Atlantic salmon at low densities ranged from 18-28% per month (see references in Hume and Parkinson 1987) suggesting that oversummer survival should range from 40-60% for a 2.5 to 3 month period. Fraser (1969) studied survival of steelhead and coho fry in stream channels where emigration and immigration was prevented. Under these conditions, survival at low density was of 90-95% for steelhead and 75-87% for coho fry. Survival at high density was 1.4-1.5% for steelhead and 6.2-10.7% for coho.

Migration Mortality: 3%. Migration mortality is potentially higher than most managers might anticipate. Coho salmon smolt survival during downstream migration (Sawada, 1993) was 5% per km (40% per 10 km). A lower value is recommended for smaller streams with fewer predators and for fish not undergoing the stress of smoltification. Note that migration mortality applies to fry and fall fingerlings only.

Fingerling overwinter survival: 60% (30-80). Winter can be a time of high stress for salmonids in streams (see references in Bustard and Narver 1975). Overwinter survival of coho in a small coastal stream was only 35% but was twice as high for fish that moved into more favourable winter habitat consisting of old beaver ponds (Bustard and Narver 1975). Survival should be set to the low end of the range in systems with severe winter conditions (drying, very cold temperatures without snow cover, high flows) and to the high end of the range for systems with good winter habitat (deep pools, backchannels).

Annual parr survival: 60% (25-85). This parameter should reflect the survival of parr at relatively low densities since surplus parr at high densities are presumed to emigrate in the spring (ie. emigration, <u>not</u> survival, is assumed to be density dependent). Parr survival is probably size dependent. Annual fry-to-parr survival for steelhead in the Keogh River was only 25% whereas annual survival of older parr was at least 85% (Ward and Slaney 1993).

% voluntarily migrating: 0, 0, 90, 100. The preferred migration age and time can be very stream specific (Northcote 1969). The default values reflect a situation where fry and fall fingerlings prefer to remain in the stream, most fish prefer to leave in the spring at age 1+ and the remainder prefer to leave at age 2+ the following spring.

4.2.8 In Lake Juvenile Survival

Maximum survival of juveniles is assumed to be equal to the survival of older fish in the input through the *Stock Dependent Parameters Window*. Survivals of juveniles are adjusted down from this maximum to take into account size and density dependent survival by using the parameters below.

Size at which survival is zero: 1 cm (1-10), size at which survival is 50%: 7 cm (7-10), curve shape parameter: 2 (2-99). These parameters determine the relationship (see view option) between the size at lake entry and the annual survival to age 2. The default values are designed for productive, monoculture lakes in the southern interior are a result of a combination of data from Stringer et al. (1980), Hepworth and Duffield (1991) and Parkinson and Johnston (data on file).

In mixed species lakes, survival of fry can approach zero and survival of larger juveniles (5-15 cm) can be much lower (10 - 20%) than that in monoculture lakes (Burrows 1993). Piscivorous fish, including cannibalistic rainbow trout seem to be a major factor in the mortality of small, juvenile rainbow (Parkinson and Johnston, data on file). Since the maximum prey size for a salmonid piscivore is about 35% of the predator's body length (Parkinson et al. 1989), survival of fish larger than 35% of the body length of the largest piscivorous fish should approach that of monoculture situations.

Proportion of size dependent mortality applied to; summer fry emigrants: 0.75, fall fingerling emigrants: 0.5. These parameters adjust annual, size-based mortality experienced by these emigrants down to account for the reduced time in the lake. The default parameters of 0.75 for summer fry and 0.5 for fall fingerlings reflect the portion of a year spent in the lake before the start of the model year in April.

Proportion increase in size-dependent mortality applied to hatchery fish: 0.1. This parameter provides the option of setting higher rates of juvenile mortality for hatchery versus wild fish in order to reflect the belief that hatchery fish survive poorly compared to wild fish. The default value of 0.1 indicates that mortality rates for hatchery fish are 10% higher than similar sized wild fish (eg. if survival of wild fish is 60%, survival of hatchery fish will be 56%). This relatively small effect reflects our belief that the relative survival of hatchery fish for lacustrine rainbow is not nearly as low as for steelhead where 0.5 would not be unrealistic (Ward and Slaney 1988, Parkinson and Slaney 1975).

Maximum yearling capacity: 1500 yearlings/ha (200-2000). Lower values of this parameter induce higher density dependent mortality by limiting the maximum number of yearlings that can survive via a saturating curve. In productive monoculture lakes, maximum yearling densities can approach 2000/ha (Johnston and Parkinson, data on file). The default value is for a productive, monoculture lake. Values for unproductive or mixed species lakes are considerably lower (Havens and Sonnichsen 1992)

4.2.9 Spawning/Fecundity Parameters

Fecundity slope, intercept: 60 egg/cm, 17 cm. The default parameters for the regression line were obtained from Allen (1951).

Minimum spawner length males, females: 20, 23 cm. Age and size at maturity are not dynamic and therefore all fish mature the following spring once they reach these lengths. These lengths can be adjusted to match lake specific data.

Spawning mortality males, females: 50%, 50%. Mature fish probably experience additional mortality due to increased susceptibility to disease (Johnstone et al 1978) or increased vulnerability to predation (Alexander and Shetter 1969). Data from Hume and Tsumura (1992) on the relative proportion of males at age 1 and 2, suggests that male maturation mortality was 80%. More recent data from a variety of lakes suggest values close to 50% (Tsumura, data on file). Much of this data is from lakes without streams and spawning mortality may be higher in situations where maturing fish have to endure the rigours of actual spawning.

Minimum spawner age, fecundity at minimum spawner age: 5, 150. These values set a minimum age by which fish are forced to mature even if they have not reached the minimum sizes above. The minimum fecundity for small fish is to ensure that maturing females do not have negative fecundities.

4.2.10 Hooking Mortalities

Hooking Mortality: 5% (2-20%). (listed in Regulations Window) Hooking mortalities are reviewed by Wydoski (1980).

Table 4.1. Summary of the recommended parameter values for SLIMM (Recommended range in brackets).

Parameter	Value	Comments
Natural survival at > Age 2.0	80% (50-90%)	
Walford intercept	28cm (15-30)	Productive, monoculture lakes
Walford Slope	66% (60-80)	
competition index	600 (400-1000) fish/ha	Productive, monoculture lakes
coefficient of variation in catch	0.107	
Var/mean ratio of Catch/angler	2.3	
Vulnerability vs. Size parameters	14 cm, 28 cm, 4	extrapolated from kokanee
catchability	0.016 (0.004-0.04)	value is based on proportion removed in 1 ha by 1 angler-day
Seasonal Effort Distribution	Spring 42%, Summer 28%, Fall 20%, Winter 10%	Kamloops area lakes
Seasonal Vulnerability	Spring 1.0, summer 0.7, fall 0.9, winter 1.0	Kamloops area lakes
Maximum Egg Capacity	300,000 /m^2	% spawning area may be very low
Rearing Capacity parameters	1.58, 0.97, 0.45	
Egg to fry survival	15% (5-40)	
summer fry survival	50% (30-80)	
downstream migration survival	3% /km	Applied to fry and fall fingerlings only
Fingerling Overwinter Survival	60% (30-80)	For average winter habitat
Annual Parr Survival	60% (25-85%)	
Survival vs. Size Curve Parameters	1.0 cm, 7.0 cm, 2	For monoculture lakes
Mortality adjustment for:	Fry 0.75 Fingerlings 0.5 Hatchery 0.1	
Maximum Yearling Capacity	1500 (200-2000) fish/ha	For productive, monoculture lakes
Fecundity Slope, Intercept	60 eggs/cm 17 cm	
Minimum Spawner Lengths	Males 20 cm Females 23 cm	All fish over these lengths mature
Spawning Mortality	Males, Females 50%	
Minimum Spawner Age, Fecundity	5, 150	All fish over this age mature
Hooking Mortality	5% (2-20%)	For unbaited, barbed hooks

5.0 MODEL STRUCTURE

5.1 Density Dependent Growth

Density dependent growth is both a fundamental driving force in the model and a phenomena which is familiar to any biologist who has observed stunted populations of trout. Our method of accounting for the dynamic response of growth follows the method of Walters and Post (1993). This method is attractive because the biological load on the lake is neither driven by biomass, where the effect of large fish is weighted too heavily, or numbers, where the effect of small fish is too great. The model uses the $\sum \text{length}^2$ which is a compromise between the two. We feel this is the best choice given the lack of empirical data on the effects of density on growth. The major assumptions of this method are as follows: 1) Growth is represented as a linear plot of length at age t versus length at age t+1 (Walford plot), 2) The intercept of this plot changes with density but the slope does not, 3) The relationship between the intercept and the $\sum \text{length}^2$ is linear. The most common non-linear Walford growth curve is one where a shift in diet produces an acceleration in growth at a threshold size (eg. piscivorous Bull trout Parkinson et al. 1977).

Walford plots are linear (eg. lines a, b, and c in Figure 5.1), and can be represented by the following equation:

$$\text{Length}_{\text{age } t+1} = \alpha + \rho * \text{Length}_{\text{age } t}$$

where α = the Walford intercept (points 1 and 2 in Figure 5.1) and ρ = the Walford slope. The intercept is the size a one year old fish would be after having spent an entire year growing in the lake. The Walford slope parameter represents the rate of fish growth. The point where the linear relationship intercepts the 1:1 line represents the asymptotic length (points A and B).

An analysis of growth data across all regions gave a mean value of 59% for the Walford slope parameter. This slope is represented by line a in Figure 5.1. A steeper slope starting at the same intercept indicates a higher growth rate of older fish relative to age 0 fish and produces higher asymptotic size (line b). SLIMM assumes that the Walford slope does not change with density.

Fish in two lakes with similar Walford slopes but different Walford intercepts also approach different asymptotic lengths (lines a and c).

The empirically derived value of 59% for the Walford slope is probably biased downward. Faster growing fish within a cohort are caught at a younger age leaving disproportionately more of the slower growing fish in older age classes. Adjusting the Walford slope parameter to change the asymptotic size (lines a and b) affects the size of smaller fish less than larger fish. Adjusting the Walford intercept affects the length at age of all fish (lines a and c).

For each year of the simulation, the Walford intercept is adjusted to account for growth rate reductions associated with intraspecific competition:

$$\alpha = \alpha_{\text{base}} /(1 + \text{Size Weighted Density}/(\text{Competition Index} * 750))$$

where α_{base} is baseline Walford Intercept (input parameter), the size Weighted Density is calculated from the current density in the lake ($\sum \text{density}_{\text{age}} \times \text{length}^2_{\text{age}}$, summed over all age classes) (see Walters and

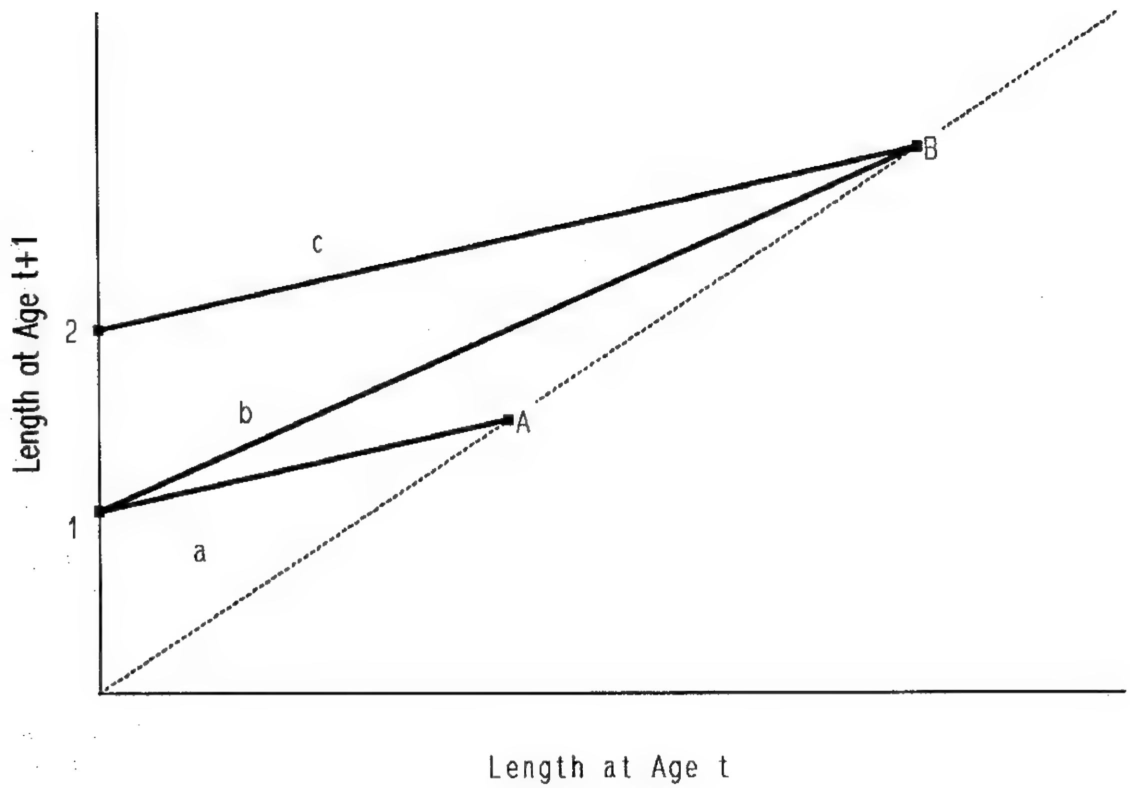

Figure 5.1. A generalized Walford plot of length at age t+1 versus length at age t. Numbers and letters refer to points and lines mentioned in the text.

Post 1993 for rationale) and the Competition Index (input parameter) is the density which reduces the Walford intercept to 50% of α_{base}.

Note the Competition Index (fish/ha) and the Size Weighted Density (fish-cm^2/ha) are in different units. Ideally, the Competition Index input parameter should actually be expressed as (fish-cm^2/ha). Fish-cm^2/ha is, however, an unusual unit of density which would have little meaning to most biologists. To avoid requiring the user to provide the Competition Index in unfamiliar units, this parameter is entered in units of fish/ha and then SLIMM makes an approximate conversion to put the Competition Index into units of fish-cm^2/ha. This conversion consists of multiplying the Competition Index input parameter by 750. If an estimate of the competition index is available in units of fish-cm^2/ha, divide it by 750 and input this value to SLIMM as the Competition Index.

5.2 Density Dependent Survival

Density dependant survival is a well established phenomena that has been documented in the stream phase of trout life history but is difficult to measure in the lake stage. The model accounts for density dependent survival in 3 stages. During the egg stage, there is a saturating relationship of maximum egg density in the gravel. The form of this relationship is :

EggDep = EggDen / (1+EggDen/MaxEggDen)

EmergeFry = EggDep * EggSurv

where EggSurv is Egg Survival (input parameter), MaxEggDen is the Maximum Egg Capacity (input parameter) of the spawning area, EggDen (#/m^2) is the density of eggs prior to deposition, EggDep (#/m^2) is the density of eggs deposited and EmergeFry is the density of emerging fry (#/m^2), with all densities expressed as a function of spawning area only. Note that the half saturation value of this curve (EggDep =1/2 MaxEggDep) is when EggDen=MaxEggDen. Egg Survival is the density independent survival of eggs that have been successfully deposited.

Limits to rearing habitat in streams (see Sections 5.5.1, 5.5.2) may also effectively induce density dependent survival. Although excess juveniles are assumed to migrate involuntarily rather than die, they may suffer much higher mortality in the lake after being forced to emigrate at a smaller than preferred size. This effect results from the size dependent survival of juveniles entering the lake (see Section 4.2.8).

The model also includes density dependent survival of juveniles during their first year of life in the lake. Survival of fish age 2 and older is assumed to be density independent. The density of age 2 fish (Age2Den) is determined by a saturating relationship involving current yearling density (YrlgDen) and maximum yearling density / ha (MaxYrlgDen) set by the user:

Age2Den = YrlgDen / (1+YrlgDen/MaxYrlgDen)

5.3 Calculation of Catch

Catch rates are determined by a number of factors and parameters in the model. The density of fish combined with the length vulnerability parameters and seasonally adjusted catchability all influence the number of fish caught.

The distribution of catch rates among anglers is assumed to follow a negative binomial distribution (Bannerot and Austin 1983, Hilborn 1985, Porch and Fox 1990). The distribution of catch rates is used to calculate the proportion of the total catch that falls within legal bag limits and can be retained. Illegal retention is assumed to be zero. These calculations assume that individuals within a party do not pool their catch and their bag limits and that the variance to mean ratio is based on catch rate data for individual anglers.

The catchability (q) parameter is used in the model to predict fishing mortality and catch. Catchability is the instantaneous fishing mortality rate (see Ricker 1975, p.8) from one unit of effort (rod-hour) in one hectare and is equivalent to CPUE/N_0, where N_0 is the number of vulnerable fish available at the beginning of the fishing season expressed as fully vulnerable equivalents/ha. The baseline q shown in the *Catch Parameters Window* is adjusted based on stock/sex-specific and seasonal multiplication factors (0-1) defined in the *Stock/Sex Dependent Parameters Window* and *Seasonal Parameters Window*, respectively.

In larger lakes the fish, and angling effort, are concentrated in a donut around the perimeter of the

lake but in SLIMM fish density (fish/ha) is specified on the basis of total area. To account for this, the baseline value of q can be adjusted using a correction factor (q_{size}):

$$q_{size} = A*(2*(A_0*\pi)^{1/2}-.005) \;/\; A_0*(2*(A*\pi)^{1/2}-.005)$$

where A is the area of the lake to be simulated and A_0 is the *Lake area associated with q* in the *Catch Parameters Window*. This adjustment assumes a roughly circular lake with a donut width of 50 m.

Catchability of is also adjusted for vulnerability. The vulnerability of each age class is depends on the current length (FL) and 3 parameters: minimum recruitable length (FL_{min}), length at 1/2 max. vulnerability (VulHalf), vulnerability-curve shape parameter (b), Section 3.3.3.2).

$$\text{Vulnerability} = (FL - FL_{min})^b \;/\; (VulHalf - FL_{min})^b + (FL - FL_{min})^b$$

5.4 Calculation of Effort

Any attempt to develop management policies for providing a diversity of fishing opportunities over a set of lakes within a large region, for example by managing some lakes for quantity production and others for quality (or catch and release, or fly-fishing only), will inevitably cause substantial effort responses and possibly shifts in fishing effort among lakes. Higher quality lakes will attract more effort until the quality of fishing is driven down to some point where other lakes look equally attractive. This process of "homogenization" via angler choices and reaction should be a matter of basic concern to managers, since it will tend to negate attempts to maintain much diversity of opportunity.

SLIMM attempts to model at least the more dramatic responses in fishing effort that are likely to result from major regulation and stocking policy changes. It assumes that these changes are due to a combination of (1) time-invariant effects of lake accessibility; and (2) time-varying effects of fish abundance, size, and regulation.

It is assumed that effort on any lake responds very rapidly to changing abundance within each fishing season, so that overall effort for any fishing season must be found by integrating over rapidly changing effort levels within the season. To model these rapid changes, we assume that abundance N decreases during the season according to the rate equation:

$$dN/dt = -qNE$$

where q is catchability and E is "instantaneous" (e.g. daily) effort; this rate ignores natural mortality during the fishing season. We then assume that instantaneous effort is roughly proportional to abundance remaining at any time, i.e. $E = kN$ where k is a response constant that depends on the region and accessibility; this assumption ignores any limit on effort that might arise over larger spatial scales (e.g., whole region) due to the size of the potential angler population (for any small set of lakes, such limits can safely be ignored). Combining these assumptions for dN/dt and E results in the rate model

$$dN/dt = -qN^2$$

for within-season abundance change. Integrating this rate equation over the fishing season then results in the following prediction models for total effort and catch given initial (spring) abundance N_0:

$$\text{Total Effort} = 1/q * \log[1 + qkN_o]$$

$$\text{Total Catch} = qkN_o^2/[1 + qkN_o]$$

The key prediction here is that total effort should vary logarithmically with abundance at the start of the season. In the model, we calculate N_0 as the sum over all fish ages of the product of density, relative vulnerabilities, and body lengths (including length here means that we in effect assume that a lake with fish twice the size as in another nearby lake will attract double the effort, if CPUE is similar in both places). Further, for the each annual calculation we replace the k constant in the Total Effort prediction equation above with a Base Effort constant that can be calculated easily from available field data; the Base Effort constant is calculated (see below) so that Total Effort will equal a regional average for any lake that has relative abundance (qN_0) that is near the regional average (and also has typical accessibility).

The effect of lake accessibility is modeled in the system by providing an "access time index" (ATI) for each lake from the lake data base, then predicting a base or average effort level for the lake from this ATI. The ATI is calculated as a sum over travel types (paved road, dirt road, 4wd road, trail, airplane, boat) of distance for each type times an estimated time per unit distance (hrs/km) for that type. Effort when fishing quality is average (at regional average CPUE) is then predicted as an inverse function of ATI, using the equation

$$\text{Base Effort} = [(e^{\text{regional base effort}} - 1)(\text{ATI}/0.7)^{-\text{regional power}}] / [2 \text{ regional base CPUE}]$$

Here, Regional Base Effort, Regional Base CPUE, and Regional Power are empirical parameters that have been estimated separately for each management region (1-8) from empirical data on effort, CPUE, and ATI. The Regional Base Effort parameter essentially represents effort that would occur in a lake having typical fishing quality (CPUE, size) if that lake had zero travel time from the nearest town in the region. The Regional Power parameter is estimated very simply as the slope of a plot of the log of effort versus log of ATI for a region. The peculiar exponential way that Regional Base Effort appears in the function arises from the mathematics of predicting integrated effort over a fishing season from the instantaneous effort response model above. The 2 in the denominator of the function arises from assuming that CPUE near the start of the fishing season is likely to be about double the mean CPUE measured in the field (i.e. the Regional Base CPUE parameter estimated from field catch-effort statistics over whole fishing seasons is likely to be only about half the CPUE at the start of each season); the back-extrapolation from field average to early season CPUE is needed in the Total Effort calculation. We chose the 2 factor for early season/average CPUE after trying the model for various lakes where total effort and catch data were available, and seeing what the factor needed to be in order to match these data.

Effort predictions from the equations above can be replaced by fixed effort levels chosen by the model user. This is useful if empirical effort data is available.

An alternative modelling approach would be to make predictions of total fishing effort over a region or group of lakes, then predict the proportion of this effort "allocated" by anglers to each lake. This more complex approach will be needed if the system eventually is used to deal with many lakes at a time, but when dealing with a few lakes at a time it is probably better to just assume that local effort is essentially unlimited (i.e. proportional to local quality of fishing and regional parameters).

5.5 Recruitment

The recruitment sub-model predicts the number of yearling recruits entering a lake based on an estimate of the amount and quality of available spawning and rearing habitat in the streams. Survival to age 2 in the lake is a function of size.

5.5.1 Habitat Capability of Streams

The number of inlet and outlet streams (available from the data base) is multiplied by an estimate of the average width and length of each stream and the proportion of the stream consisting of rearing and spawning habitat to estimate the amount of available production area. Once the amount of habitat is defined, maximum capacities for the various life-history stages are used to translate amount of habitat into habitat capability at a given life-history stage.

The numbers of emerging fry are limited by a saturating relationship (see Section 5.2) involving maximum egg capacity of the spawning area.

Stream habitat capability for juvenile rainbow trout is determined by either a regression model or user defined habitat capabilities (perhaps involving an alternative regression model). The SLIMM regression sub-model predicts fish numbers per 100 m^2 unit (FPU) using a regression developed by R.A. Ptolemy (B.C. Fisheries Branch, 780 Blanshard St., Victoria, B.C.):

$$FPU / 100m^2 = Constant - K_1 \times Log_{10} (Juvenile\ Weight) + K_2 \times Log_{10}(Alkalinity)$$

Alkalinity is used as a measure of stream productivity. To use this with the data from the small lakes data base, we estimate stream alkalinity from Ph measured in the lake using a standard titration curve. Juvenile sizes can be entered as parameters by the user. The numbers predicted by the Ptolemy relation represent the maximum values that would be expected in high quality habitat. These can be reduced in a simple multiplicative way using a subjective index of habitat quality.

5.5.2 Stream Recruitment

Actual egg deposition declines with potential egg deposition (Section 5.2). Fry numbers are equal to egg deposition times egg survival.

Following emergence fry may either choose to remain in the stream or migrate. Juveniles can migrate at a variety of sizes and ages:
1. Fry can migrate immediately to the lake,
2. Fall fingerlings migrate to the lake after rearing for the summer,
3. Age-1+ juveniles migrate in April after over wintering, and
4. Age-2+ juveniles migrate in April after over wintering a second time.

At each migration time, emigrants includes both voluntary emigrants plus the involuntary emigrants. Involuntary emigrants are excess fish forced out of the stream once the habitat capability of the stream for a particular life history stage is reached. At each migration time, voluntary emigrants are removed from the stream and the remaining number of juveniles minus the habitat capability of the stream is equal to the number of involuntary emigrants. Note that involuntary migration increases with density but mortality rates in the stream are constant. Emigrants that reach

the lake are subject to size dependant mortality.

Migration mortality is applied to fry and fall fingerlings migrating to the lake. If migration mortality is 3% per kilometre then juveniles in a 6 km long stream will migrate an average of 3 km and thus experience 8.7% mortality. Migration mortality of age-1+ and -2+ emigrants is assumed to be minimal.

5.5.3 Lake Recruitment

Once stream emigrants reach the lake, their maximum survival is equal to the annual survival of adults (Section 3.3.3.1). A series of adjustments (Sections 3.3.3.7, 4.2.8), are made which decrease the survival of lake immigrants and stocked fish up to spring, age 2:

1. Annual survival of juveniles is size dependent.
2. Annual survival fry and fall fingerlings is discounted because they spend less than a full year in the lake.
3. Survival of hatchery fish is reduced.
4. A saturating relationship determines the number of yearling fish surviving to age 2 as a function of the density of yearlings at the beginning of the year and a maximum yearling capacity (see Section 5.2). Age-2 emigrants are treated as large age-1 emigrants.

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